# Stereo Matching Technique using Belief Propagation

## Annual Progress Seminar-III


By

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# Outline

# Introduction to **Stereo matching or Stereo Vision problem**

- The stereoscopic images or stereo pair consists of two images of the same scene taken slightly horizontally separated points from the left view and the right view.
- The parallax effect also present in stereoscopic images,A parallax is ability to see an object at two different views.
- Due to parallax effect in stereoscopic images , objects near the camera will represent more to the right in the left image and more left in the right image.
- The horizontal displacement of an object left and right view depends on the distance from the object to the camera view points.

# Introduction to Stereo matching


Figure: The principle of stereoscopic images

Objects close to the camera will be placed more to the right in the left image - and more to the left in the right image.

Faraway objects, such as the sun and the cloud, will be located at approximately the same position in both images.

# Introduction to **Stereo matching or Stereo Vision problem**

- To find the matching pixel in left and right image for stereo pair image is known as **stereo vision, stereo correspondence or stereo matching.**
- In stereo matching aim is to find the matching pixel for a stereo pair image as input image which consists of left and right image and result of finding matching pixel is saved as Depth map or disparity map.
- The disparity is horizontal distance between two matching pixel and horizontal pixel distance for each pixel coordinates is nothing but Disparity map.

# Introduction to Stereo matching

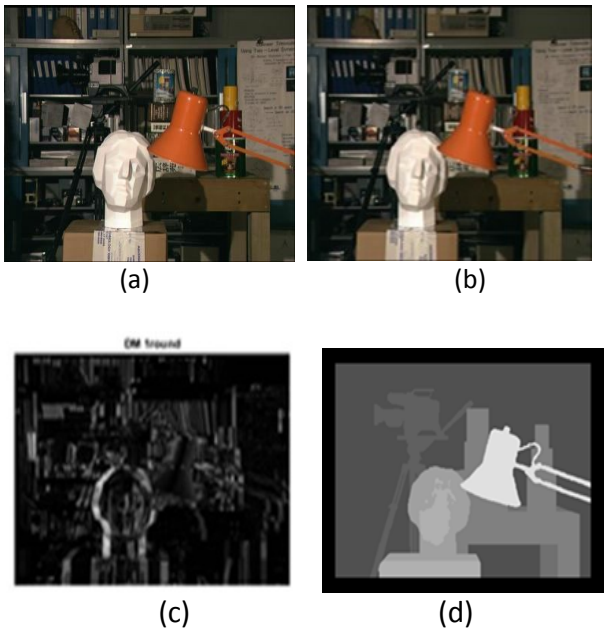



Figure: (a)Left Image (b)Right Image(c)Depth map by Global Method(d)Ground truth

# Classification of Stereo matching Algorithm

- The stereo algorithms based on intensity profile are **Area-based and Feature- based algorithm**
- The constrains in area- based algorithm is to find the optimal size of the window
- The feature-based algorithms is restricted to using only specific feature,that only yield sparse disparity maps
- Global algorithm are based on baysian approach finds disparity as a energy minimization problem
- Global stereo algorithm are **Graph cut and belief propagation**

# Applications of Depth Map

- View Interpolation can done using stereo pair and Depth map


Input


Depth Map


Novel view

- Image sequence analysis in entertainment,information transfer and for reconstruct 3D model sequences

# Applications of Depth Map

- Used for robot navigation and depth information is used for object recognition to separate occluded image components

- Scientific applications such as extracts information from aerial surveys and for calculation of contour maps
- Gaze correction for video conferencing

# The stereo matching problem can be expressed in terms of Markov

- The markov network model is a probability graphical model which consists of undirected graph of 'n' nodes with pair wise potentials as compatibility function
- Y is evidence or observed state node,$X\_s$ is hidden node state,state of each nodes $'i'$ represent as **X**_i for given evidence,To find most likely set of nodes $\{X\_1, X\_2, X\_n\}$ for given evidence 'Y' and compatibility between neighboring nodes can be expressed as a joint probability distribution function of $n$ nodes.
  - P (X_1, X_2, X_n/Y)
    $$= \prod_{Allnodes\mathbf{s}} \Phi(X\_s, Y) \prod_{(Allneighboringofnodes\mathbf{s,t})} \Phi(X\_s, X\_t)$$

# The stereo matching problem can be expressed in terms of probability theory

- Markov network model is analogous to Bays theorem
- According to Bays theorem :P(X/Y) = P(Y/X)*P(X)/P(Y)
- Y is stereo set and X is disparity map,$P(Y)$ =1(assumption)
- The disparity map can be obtained by maximizing probability of disparity map to stereo set i.e.$P(X/Y)$ and probability can be expressed in terms of Datacost and smoothness cost functions

# Mathematical Representation of Global stereo Algorithm

Table: Stereo matching problem as probability theory and markov network

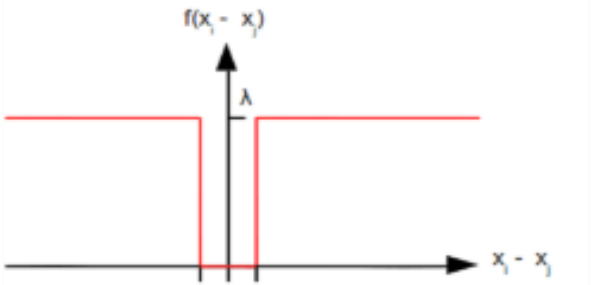
| S.No | Markov network | Probability Theory |
|---|---|---|
| 1 | Maximizing joint probability distribution i.e$P(X_1, X_2, ..X_n/Y)$ | Maximizing probability of disparity map to stereo set i.e. $P(X/Y)$ |
| 2 | Markov state | Set of pixels in with assigned disparity value |
| 3 | For given Evidence Y | For given set of stereo images |

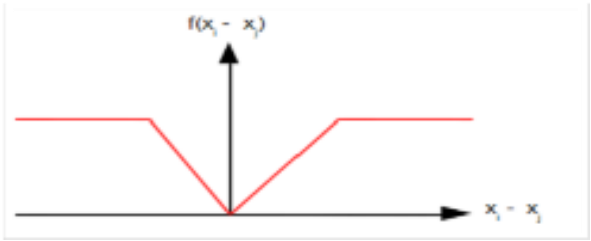
# Mathematical Representation of Global stereo Algorithm

- To find Maximum A Posteriori (MAP) estimation in markov network is NP hard means to get a solution for such problem takes unthinkably long time because each pixel (node) in disparity map can take any value in disparity space (state)
- For example for Tsukuba image of size 384 x 288=110592 pixel with 16 disparity levels gives $16^{110592}$ combinations,So it is difficult to find solution
- Belief Propagation algorithm is approximate solution to estimate Maximum a Posteriori (MAP) in reasonable amount of time

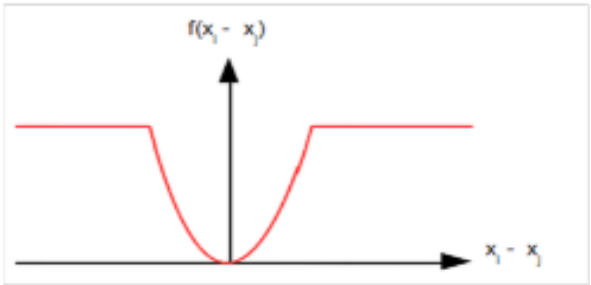
# Model representation for Stereo algorithm

- The probability of stereo set to disparity map .i.e. P(Y/X) and the probability of disparity map i.e. P(X) is expressed as matching cost term and smoothness cost term.
- The data cost is based on the intensity differences between the two pixels. The Sum of Absolute Difference (ABS) or Sum of Square Difference (SSD) functions are used as data cost
- smoothness cost models are Pott's model, linear and quadratic models
- The Pott's model is a binary penalizing function with a single tunable variable. This value controls how much smoothing is applied.
- The linear and quadratic models have an extra parameter K. K is a truncation value that caps the maximum penalty.




Truncated linear model $f(n) = \lambda \times \min(|n|, K)$



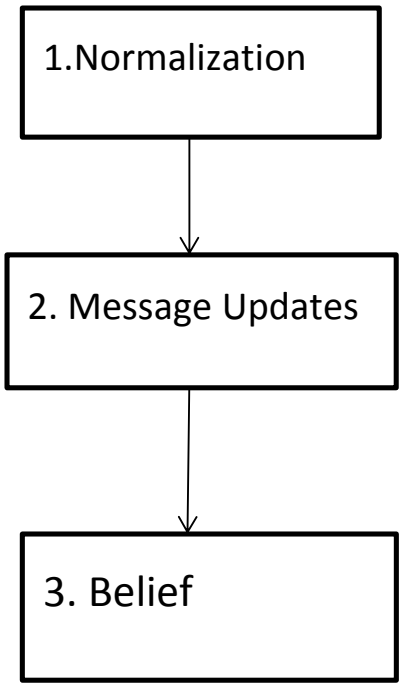

Truncated quadratic model. $f(n) = \lambda \times \min(n^2, K)$

# Belief Propagation Algorithm

- The belief propagation algorithm was proposed by Pearl in 1988 for finding exact marginal's on graphs known as trees that contain no loops.It can be applied to graphs with loops also
- The Loopy belief propagation is an approximate inference algorithm which keep passing the messages around markov state or node until stable belief state is reached,It is iterative algorithm, messages will converge on doing iterations.
- There are three main steps finding Maximum a Posteriori (MAP) estimation or beliefs in Belief Propagation algorithm
  1. Normalization
  2. Message update or generation
  3. Finding belief

# Belief Propagation Algorithm

- Steps to find marginal in Belief Propagation algorithm




1. Normalization is required ,To avoid While continuously multiplying probabilities, messages becomes zero and hits the floating point limits.

2. Messages are updated by joint probability of data cost, smoothness cost and for all incoming messages which are marginalized over given disparity is done in second step.

The final message in message update or generation step is a vector and size of the vector depends on disparity value.

3. the values of belief can be found either by Max Product belief propagation or by Minimum of Sum

Figure: Pott's model, Linear and Quadratic models

# Literature Survey on major contribution in the field of stereo matching using MRF and BP

- Comparison of Graph cuts with Belief Propagation for stereo, Using Identical MRF Parameters[1]
  1. The disparity image can be achieved by modeling Markov Random Field and by using optimization algorithm such as Graph cut and Belief Propagation
  2. The solutions produced by Graph cut are smoother while accelerated Belief Propagation algorithm was faster.
- Efficient Belief Propagation for Early Vision[2]
  1. Technique used is difference between two labels rather than on particular pair of labels
  2. Modified message update scheme where nodes are split into two Messages and updated alternately.

# Literature Survey on major contribution in the field of stereo matching using MRF BP

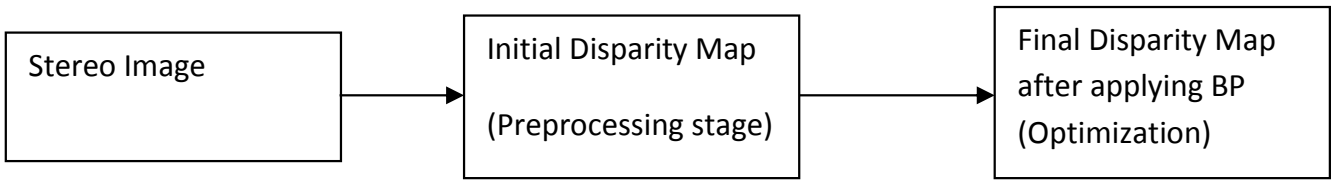
- Low Memory Cost Block Based Belief Propagation for Stereo Correspondence[3]
  1. Block based BP algorithm directly partitions image into separated independent blocks, convergence criteria is important for each block.
  2. The convergence is according to equivalence of all disparities for each node in a block over successive iterations
- Hardware-Efficient Belief Propagation[4]
  1. MRF is divided into multiple regions known as tile and iterations are done on those regions.
  2. Robust function is used as smoothness cost.

# summary of literature survey

| Year. | Method | Further study |
|---|---|---|
| [2003] | Comparative study of Graph cut,BP | Improving formulation MRF |
| [2004] | Different MUS of BP | MUS schemes for other cost functions |
| [2007] | 2D BP Graph is divided into blocks | processing of finished block and unfinished block |
| [2009] | Tile based BP Fast message construction | Tile based scheme can be studied for different smoothness cost functions |

# Implementation of Global Stereo Algorithm

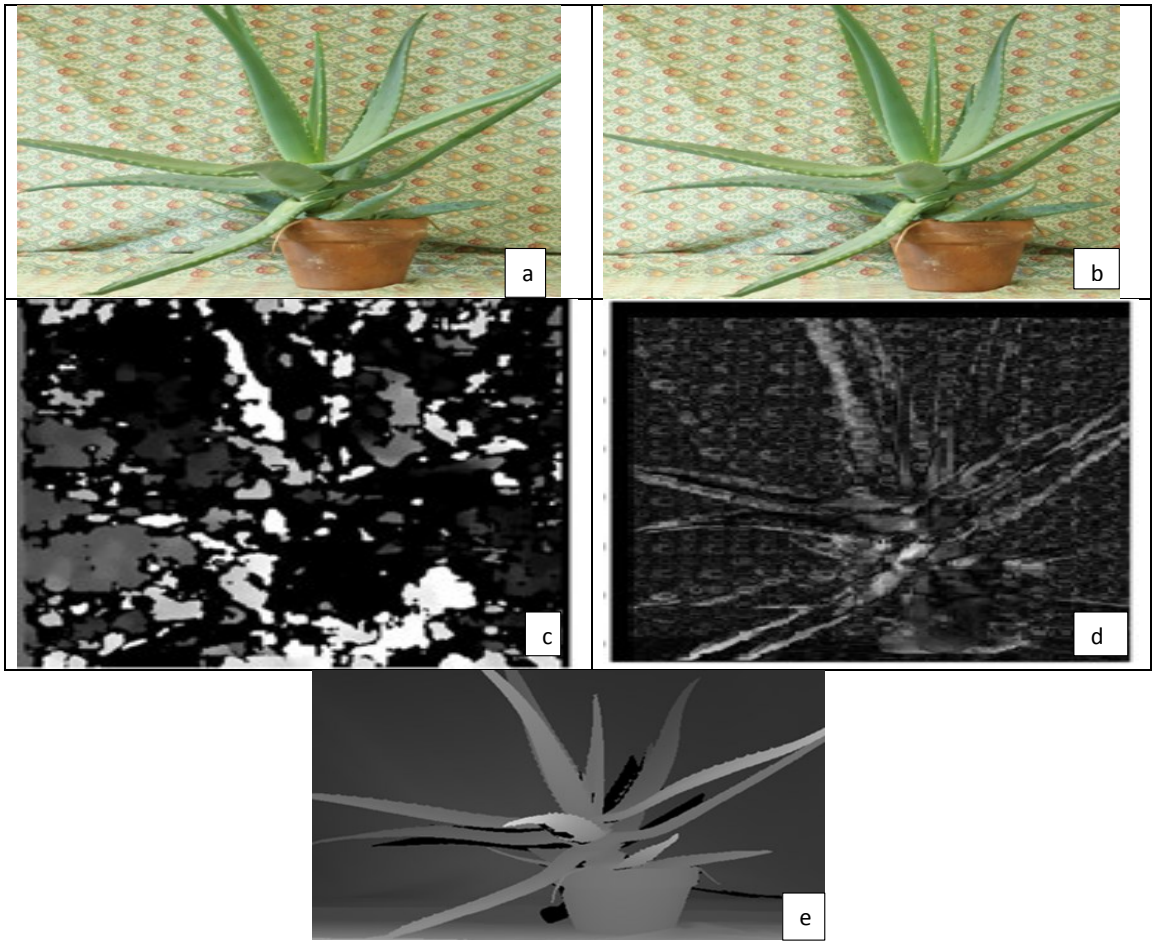
- Block diagram for implementation of Global Stereo Algorithm using Belief Propagation




- Stereo images(Rectified images) are taken as input
- The software used for simulation is MATLAB version 2015

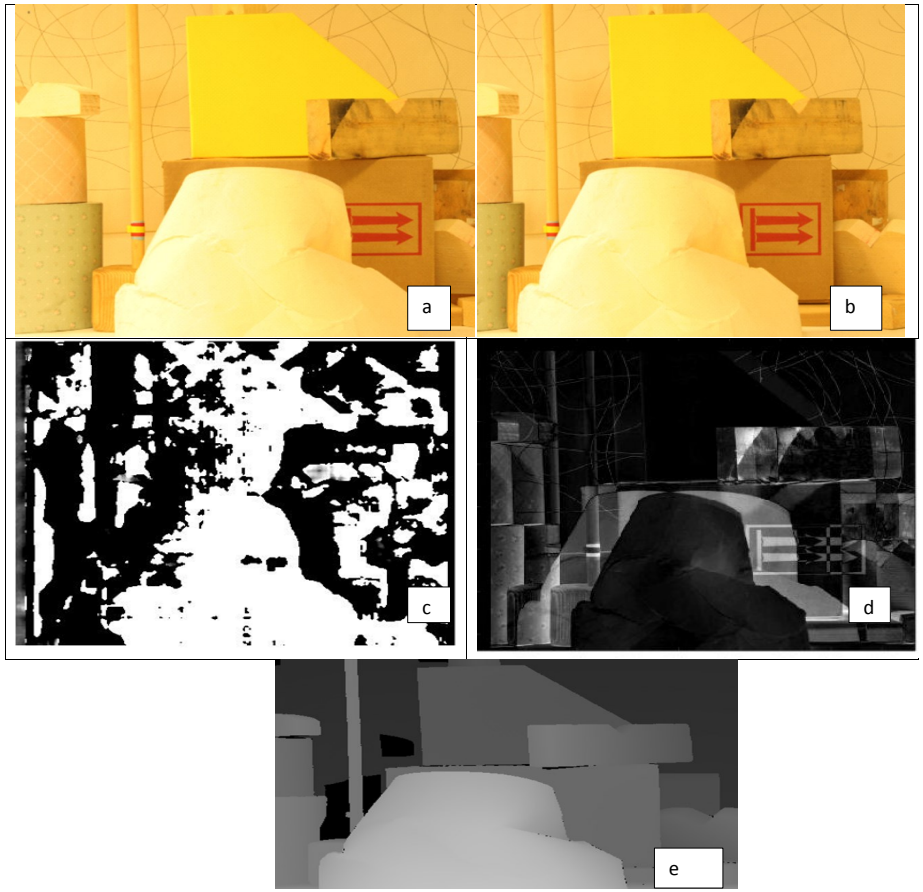
# Implementation of Global Stereo Algorithm

- To find Initial depth map as a preprocessing stage two methods are used.
- First one is using MATLAB inbuild function "DisparityMap" in computer vision toolbox
- Second method is minimum index method by using sum of absolute difference function
- Initial depth map generated by both methods are optimized by Belief Propagation algorithm




(a)Left Image (b) Right Image (c) Initial Depth Map
(d) Depth Map by BP (e) Ground Truth

Figure: Representation of pot stereo image,Initial D.M by MATLAB function and it's depth map

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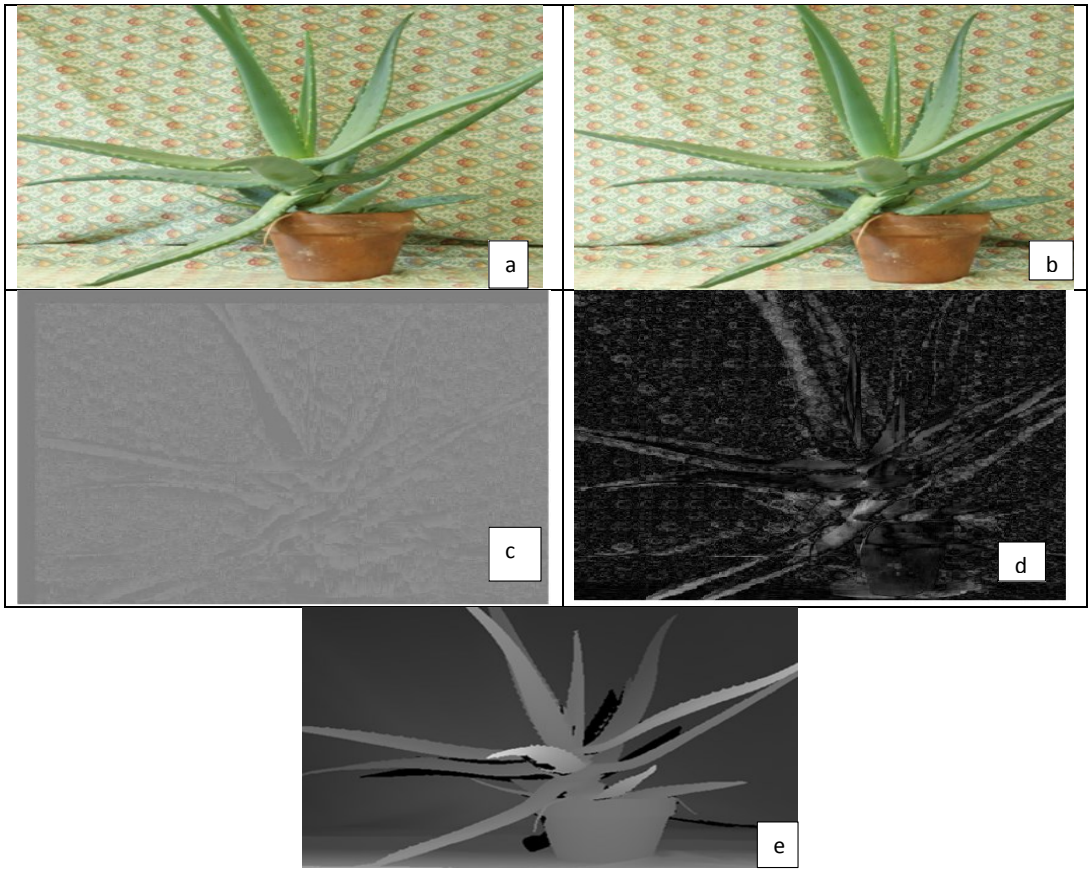
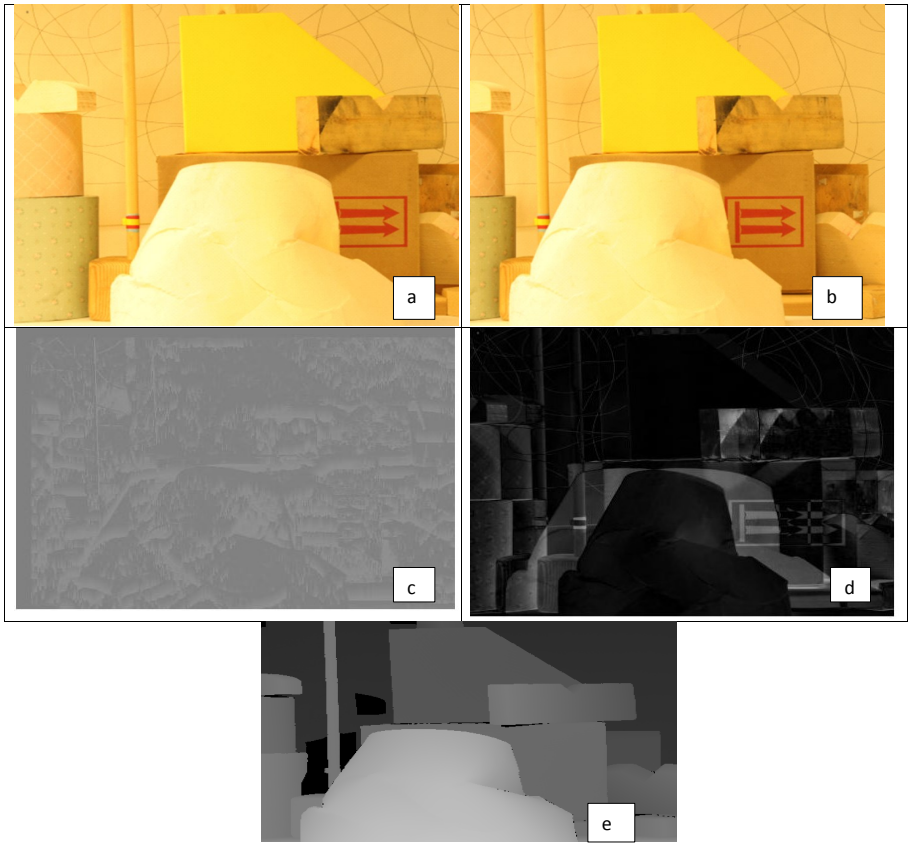



(a)Left Image (b) Right Image (c) Initial Depth Map
(d) Depth Map by BP (e) Ground Truth

Figure: Representation of plant stereo image Initial D.M by Minimum Index method and it's depth map



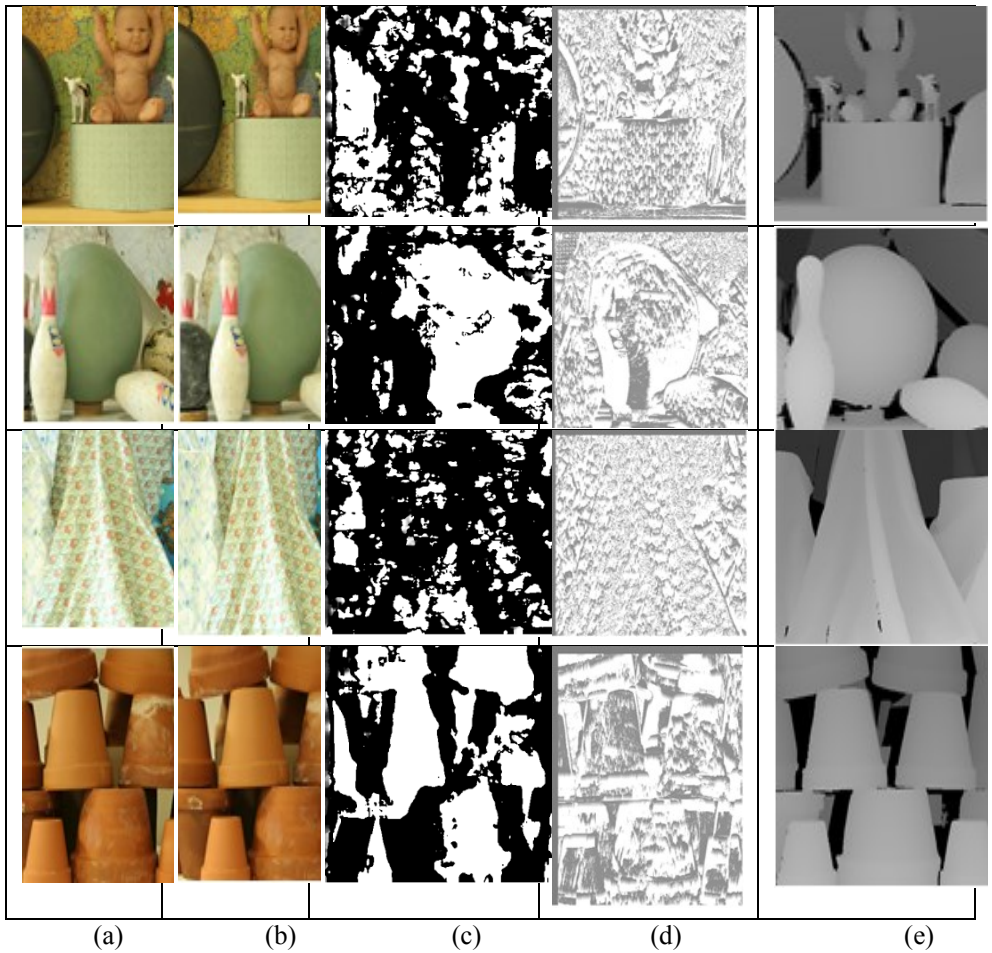

(a)Left Image (b) Right Image (c) Initial Depth Map
(d) Depth Map by BP (e) Ground Truth

Figure: Representation of pot stereo image Initial D.M by Minimum Index method and it's depth map

- The label or disparity level at present which is fixed to 16
- The issues faced at this stage is that ,after optimizing depth map with Belief Propagation algorithm some portion in depth map are overlapped
- At this stage concluded that logical error exists in the programme and it was difficult to solve
- At this moment ,The depth map generated by minimum index method and standard method are compared ,Manuscript is send to scopus indexed journal,awaiting for acceptance

- The manuscript title , " Simplistic approach for Computing Disparity map" is submitted to Malaysian Journal of Computer Science on 14 October 2017
- A simple technique called 'minimum index method' is used for the computation of disparity map which is compared with popular method available in most of standard computation tools in Matlab.
- The standard method used is inbuild function 'DisparityMap' from computer vision tool it box in MATLAB.
- The simulated results shows that in minimum index method objects in depth map are better recognizable than standard method. The mean square error less in minimum index method than standard method.

- The stereo images for testing are from data sets 2014 of Middlebury computer vision web site (vision.middlebury.edu).
- Baby, Blowing ,Cloth and Pot are considered as test stereo images and these images are having ground truth.




(a)Left Image (b) Right Image (c) Depth map by Semi Global Block method (d) Depth map by Minimum Index Method (e) Ground truth

Figure: Representation of Stereo input images and Depth maps

# Mathematical Representation of Global stereo Algorithm

Table: Mean Square Error for both methods for test images

| Stereo Image | Minimum Index Method (MSE) | Standard Method (MSE) |
|---|---|---|
| Baby | 2150 | 16950 |
| Bowling | 3074 | 19526 |
| Cloth | 2177 | 20137 |
| Pot | 3143 | 17229 |

- The functions are defined in MATLAB for each step to get disparity map
- The disparity levels or labels are 0 to 15
- DataCost using linear model ie.sum of absolute difference
- SmoothnessCost using truncated linear model, truncated at 2,with$\lambda$ =20
- Message update is Min-sum Optimization algorithm
- Problem faced at this stage is that run time to do 1 iteration takes more than 1 hour and DEPTH MAP are not refined on doing iterations

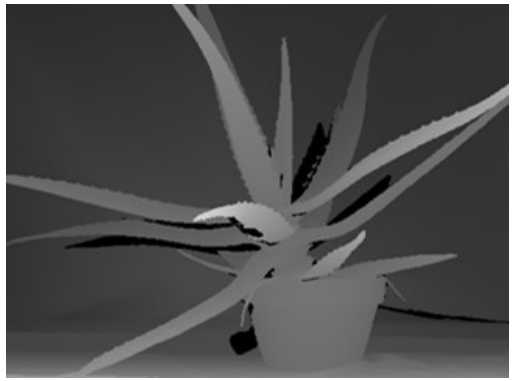
# Results

Depth Map using BP for tsukuba

Ground Truth map for tsukuba

# Results

Depth Map using BP for aloe Vera plant



Ground Truth map for aloe Vera plant

# Conclusion

- Literature survey is done to find Gap,So that to do further research either to reduce runtime of iterative Belief Propagation algorithm or to find better Depth Map
- The clarity of Depth Map not only depends on either linear or quadratic model used as well as depends on the values of parameters like $\lambda$(tunable variable) and k is (truncation variable)
- The pointers used for message update function in MATLAB not able to store the updated messages because of this problem not able to get refined depth map

# Future work

1. The message update function can be done in C-Programming and interface with MATLAB
2. The belief propagation algorithm is tested on different stereo images

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# Thank You...